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# The Nature of Science and Technology in Teacher Education

Bodil Svendsen

*The problems that exist in the world today cannot be solved by the level of thinking that created them (Albert Einstein)*

## Abstract

This chapter is about the Nature of Science (NOS) and the Nature of Technology (NOT) in education. Science includes the systematic study of the structure and actions of the physical and natural world through observation and experiment, and technology is the application of scientific knowledge for practical purposes. NOS and NOT have been used to refer to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge. These characterizations, nevertheless, remain general, and philosophers of science, historians of science, and the same goes for NOT. Subsequently, an individual's understanding that observations are constrained by our perceptual apparatus and are characteristically theory-laden is part of that individual's understanding of the NOS and NOT. In general, NOS and NOT refers to principles and ideas which provide a description of science and technology as a way of knowing, as well as characteristics of scientific knowledge. Many of these intrinsic ideas are lost in the everyday aspects of a science classroom, resulting in students learning misaligned ideas about how science is conducted. Understanding how technology relates with science and society is critical for individuals to make informed personal and societal decisions. Nevertheless, in most STEM education contexts, learning about technology typically only means learning how to be an efficient user or, perhaps, an informed competent designer of. A meaningful technology education stresses that science education efforts also teach students about NOT. Essential questions like what technology is, how it is related to, yet distinct from, science, how it shapes and is shaped by society, and perhaps most importantly, how technologies impact the way individuals think and act.

**Keywords:** NOS, NOT, IBL, education, scientific- technological innovation

## 1. Introduction

### 1.1 A historical recall

The history of NOS and NOT began as early as 600–200 B.C. This was the era when the country of Greece developed as the center of learning of Western civilization. Aristotle (384–322 B.C.) was the leading philosopher of this period. The science of Aristotle is the ancestor of the modern science. Aristotle presumed observations held the key to understanding the developments of Earth and its life

forms [1]. Aristotle believed in cause and effect, and that to understand an effect we need to understand its origins and the purposes of those origins. The science of Aristotle was based on a comprehensive study of the natural world, and he tried to rationally connect his observations to the world he lived in.

The further major development of NOS and ideas about NOT took place in the Renaissance. Between the time of Aristotle and the beginning of the Renaissance, little evolution was made in scientific thinking. The Renaissance brought with it a spirit of curiosity and experimentation unseen since the time of Aristotle. The renaissance was a period of excessive intellectual growth and achievement that began in the fourteenth century and extended into the seventeenth century.

A major achievement of the Renaissance was to diverge from the idea that the universe centers on human beings [1]. Humans were believed to be part of a universe that included Earth. Renaissance scientists rejected the idea that there was a hidden purpose behind everything. An apple did not fall to the ground because of its own purpose, it fell to the ground because of gravity. The gravity is a property of matter, that it is a force between two objects. For the people of the Renaissance to realize that Earth and its life forms have properties that can be studied and understood is possibly the greatest scientific success of the Renaissance.

Since the period of the Renaissance and until today, science has developed through an unbelievable evolution. Together with discoveries and inventions the scientific method has evolved. A main feature of the scientific method is scientists attempt to look at the natural world objectively. This means that scientists try to see things as they are, without letting values or beliefs color their view [1]. This is quite unlike the early science and the science of the Renaissance. Scientific technological knowledge today is based on explanations that are confirmed by experiments [2]. The goal of science is to answer questions about our world by creating the best possible explanation that agrees with experimental results. To make findings accessible to others, scientists report all experimental results and the procedures used to obtain those results. In this way, other scientists can redo experiments to see if they get the same results. Scientists often check the work of other scientists in this way, this is what the nature of science and technology is all about [2].

## **2. The nature of science in education**

It is quite common to introduce textbooks in science education with a section outlining “the scientific method”. This is usually done by introducing a step-by-step process that apparently must be followed in order to conduct scientific studies, according to the science curriculum [2]. A conceivable risk in this approach is not only that learning the scientific method is a misconception for students, but that it is also quite limiting within its range. Scientists usually do not go through the method chronologically. They often bounce around, conceivably forming a new hypothesis during experimentation. Students should learn to make good observations, inferences and understand the significant role that observations and inferences play in the development of scientific knowledge. The use of an inquiry approach for teaching within the curriculum can be supported by the fact that science is a process for generating knowledge [3]. The process rests both on making careful observations of phenomena and on creating theories for making sense out of those observations. Change in knowledge is expected because new observations may challenge dominant theories. No matter how well one theory explains a set of observations, it is possible that another theory may fit just as well or better or may fit a still wider range of observations [2].

It is important to be aware of how nature of science is being taught and why, different teaching strategies, opportunities, unique mental processes and good

examples to do this within a national curriculum that possibly not acknowledge its importance. This is challenging, yet important, as it is very often NOS themes that students find engaging and which provide a narrative to their experience of science [2]. Knowledge of NOS is as least as important in creating scientifically literate citizens as factual content knowledge.

### **3. The nature of technology in education**

The last 30 years have been a period that has had a major impact on how technology takes radical place in human life. It is rather reasonable to say that computer technologies and the Internet are necessary for people. New methods based on Artificial Intelligence technologies generate the creation of new ideas on the horizon and propose alternative solutions to numerous different problems. Technology involves an understanding of what technology is, how and why technology is developed, how individuals and society direct, react to, and are sometimes unwittingly changed by technology. It is important to teach NOS and NOT because [2]:

- Of the need for future scientists, engineers, technologists, and others who will need a strong science and technology background for their future work.
- It is important aspect of modern culture and everyone should appreciate this aspect of culture.
- A knowledge of science and technology is needed for citizenship in modern technological societies.

Understanding how technology interacts with science is important for students to make informed personal and societal decisions. Though, STEM education contexts often learn about how technology can be useful for us to use. However, a robust technology education demands that science education efforts teach students about the nature of technology (NOT) [4]. Here it is central to learn what technology is, how it is related to, yet distinct from, science, how it shapes and is shaped by society and how technologies impact the way individuals think and act.

### **4. A scientific- technological approach**

The process of science and technology is to challenge ideas through research [4]. Science and technology are based on fact, not opinion or preferences [2, 4]. This process focuses only on the natural world. When trying to describe the history of NOS and NOT, it can be useful to think of science and technological development as a culture in just the same way that we think of different cultural worlds such as art and music. We need to understand and talk art or music when we enter these worlds. In the same way, we need to be able to understand and talk science and technology [5]. There are made some characteristics of the nature of science that are reasonable [2, 4, 6]:

- Science is socially and culturally embedded.
- Science is subjective and theory laden
- Scientific knowledge is tentative (subject to change)

- Science is empirically based
- Science take note of the relationships between scientific theories and data
- Science is inferential, imaginative and creative.
- Science pay attention to the difference between observation and inferences.

Science trusts that the things and actions in the universe happen in consistent patterns that are understandable through careful, systematic study [6]. Science also assumes that the universe is a big single system in which the basic rules are the same everywhere. Knowledge gained from studying one part of the universe is applicable to other parts. For instance, the same principles of motion and gravitation that explain the motion of falling objects on the surface of the earth also explain the motion of the moon and the planets. With some modifications over the years, the same principles of motion have applied to other forces and to the motion of everything, from the smallest nuclear particles to the most massive stars, from chemistry to nanotechnology [4].

Science is a process for producing knowledge. This process depends on making careful observations of phenomena and on inventing theories for making sense out of those observations. In science, the testing and refining and sporadic discarding of theories, whether new or old, go on all the time [5]. Though, scientists discard the notion of achieving absolute truth and accept some uncertainty as part of nature, most scientific knowledge is well-made [1, 2]. The adjustment of ideas is standard in science, as powerful constructs tend to survive and grow more precise and to become widely accepted. For instance, in formulating the theory of relativity, Einstein did not reject the Newtonian laws of motion, but rather showed them to be an estimate of limited application within a more general concept. Change in knowledge is therefore to be expected because new observations may challenge current theories.

There has been technology as long as there have been people in the world, the techniques of shaping tools are taken as the main evidence of the beginning of human culture [4]. Overall, technology has been an influential power in the development of civilization. Technology—like language, arts, rituals, values, and business is an essential part of a cultural system and it both forms and replicates the system's values. In the world today, technology is an intricate social enterprise that includes research, design, craft, finance, manufacturing, management, labor, marketing, and maintenance. We use technology to try to change the world to suit us better.

Technology covers our capabilities to change the world: to cut, shape, or put together materials; to move things from one place to another; to reach farther with our hands, voices, and senses. However, the results of changing the world are often complex and inconsistent. They can include unexpected profits, unexpected expenses, and unexpected dangers. This may fall on different social groups at different times. Anticipating the effects of technology is thus as significant as evolving its capabilities [7].

Key principles in the area of Nature of Technology:

- Technological development involves creative thinking.
- Technology is constrained by laws of nature, such as gravity.
- Scientists are concerned with what exists in nature; engineers modify natural materials to meet human needs and wants.



- Technologies developed for one purpose are sometimes adapted to serve other purposes.
- The pace of technological change has been increasing.
- Science, technology, engineering, mathematics, and other disciplines are mutually supportive.
- Tools help people do things efficiently, accurately, and safely.
- Technology and its relationship with nature

Technology is object of studies by a wide range of philosophers, historians and sociologists, and their inquiries provide educators with extensive guidance as to which ideas about the NOT have value and which have not.

## 5. Scientific and technological inquiry

The matter of scientific and technological inquiry is important, and so is the importance of how to teach NOS and NOT [5, 7]. The various scientific disciplines are alike in their dependence on evidence, the use of hypothesis and theories, the kinds of logic used, and much more. However, scientists differ greatly from one another in what phenomena they investigate and in how they perform their work; in the reliance they place on historical data or on experimental findings and on qualitative or quantitative methods; in their recourse to fundamental principles; and in how much they draw on the findings of other sciences.

There is no fixed set of steps that scientists constantly follow to reach scientific knowledge. Nevertheless, there are certain features of science that give it a distinctive character as a mode of inquiry. Although those features are especially characteristic of the work of professional scientists, everyone can exercise them in thinking scientifically about many matters of interest in everyday life [2]. Scientists attempt to make sense of observations of phenomena by creating explanations for them that use, or are consistent with, currently accepted scientific principles [1]. The credibility of scientific theories frequently originates from their ability to show relationships among phenomena that earlier appeared distinct.

## 6. Inquiry- based teaching in science and technology education

In schools education, teaching of NOS and NOT can be done in an inquiry way, using inquiry-based learning (IBL) or by using problem-based learning (PBL) [3, 8]. IBL is basically about teachers teaching students to have a better understanding of the world in which they work, communicate, learn, and live. Teaching strategies that actively involve students in the learning process through inquiries are more likely to increase conceptual understanding [8, 9]. IBL is to be *the intentional process of diagnosing problems, critiquing experiments, distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments* [10, 11]. Questioning and finding answers are important in IBL as aids to effectively generating knowledge [3]. However, IBL is not just about asking questions and discussing solutions; it is a way of adapting data and information into useful knowledge. Teaching strategies that actively engage students in the learning process through inquiries are more likely to increase conceptual

understandings, and there can be variable amounts of direction from the teacher, in both open and guided inquiry [3, 10, 11]. However, the debate among researchers concerning the effect of IBL to increase students' understanding of concepts is complex and the discourse around this has been a matter of discussion for many years.

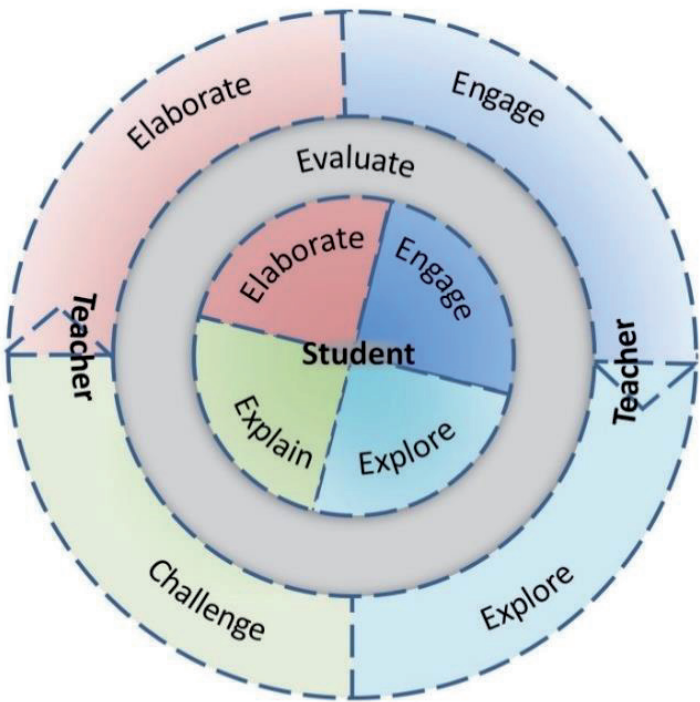
Problem-based learning (PBL) is an instructional approach that has been used successfully since the seventies and continues to gain acceptance in multiple disciplines [8, 9]. It is an instructional (and curricular) learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem. Innovative approaches to education such as problem-based learning (PBL) and inquiry-based science learning (IBL) situate learning in problem-solving or investigations of complex phenomena [10, 11].

*When students are developing their understanding of the natural and made world around them, then, like scientists, they can use inquiry to arrive at ideas and theories that help them explain what they observe. Students also have to change their ideas as they encounter new and conflicting evidence. And, like scientists too, they do not begin from a clean slate, but from what they already know and the ideas they have already [12].*

Inquiring and discovery of answers are important both in PBL and in IBL as aids to create knowledge [10]. IBL and PBL argues for self-directed learning, with students taking more charge of their learning and the development of skills in self-reflection [8, 10, 11]. IBL and PBL are not just about asking questions but are a way of transforming data and information into valuable knowledge.

## 7. The 5E-model in education

The 5E- model has its origins in the Biological Sciences Curriculum Study (BSCS), in which American scholars developed educational programs and research on teaching and learning in science [13]. As a tool for teaching inquiry and problem-based, teachers can use the 5E model (see **Figure 1**). The five E's are the first letters



**Figure 1.**  
The 5E model [3, 13].

in the words *engage*, *explore*, *explain*, *elaborate* and *evaluate*. The intention of the model is to be used for planning, implementation and evaluation of learning and teaching. The 5E model [3, 13] can be used to support teachers in the planning, implementation and evaluation of teaching. The model can be supportive in making inquiry-based teaching explicit and targeted.

Initially, the 5E model was an instructional model for inquiry-based science teaching (IBST) [13]. The model has been further developed at the Norwegian University of Science and Technology (NTNU) as a tool for reflective learning and teaching, using an abductive process of reflection in the cognitive learning of both teachers and students [3]. The learning process moves back and forth between the crosshatched areas as the cognitive process proceeds and develops. The 5E model is shown as a model of reflective learning and teaching (**Figure 1**).

By defining clear education aims for teaching, teachers can use the model as a reflection tool for designing, planning, implementing and evaluating their teaching sequences. Both teachers and students can determine learning objects. By shaping clear learning aims for teaching, teachers can use the model as a reflection tool for designing, planning, implementing and evaluating their teaching sequences with gifted students.

**Table 1** shows the phases in the 5E-model, and the roles of the teacher and students.

In the 5E model the teachers teach by *engaging* the students with a starter. A starter should be both motivating and related to phenomena that students can relate to, like everyday phenomena. The students' former knowledge is accessed by the teacher or the curriculum, and aids students to become engaged in a concept using short activities, or introduction to phenomena in order to endorse interest and provoke prior knowledge [13]. Activity refers to both mental and physical activity [3, 13]. The activities of this phase make connections to earlier understandings and expose students' misunderstandings, they should serve to affluence cognitive differences. After the activities have engaged the students, the students need time to *explore* the ideas. Activities should be designed for the students to have shared, actual understandings upon which they continue expressing concepts, processes, and skills. The students work actively with the material (read, write, investigate, play, observe, etc.) and add knowledge and skills to reach new learning goals. This level is authentic and hands on, and the use of physical materials and existing experiences is important, but not essential. The aim of creating cognitive curiosity is to establish experiences that teachers and students can use later to introduce and discuss concepts, processes, or skills [13, 14]. Explanation provides lead-ins for teachers to introduce a concept, process, or skill. The students *explain* their understanding of the concept. An explanation from the teacher may guide them toward a deeper understanding, which is an important part of their new knowledge [3]. By enabling activities that build on the knowledge and skills the student already owns, and allow students to reflect, discuss, read and write to accomplish the learning aims, the teacher can present new thoughts that challenge student's conceptual understanding [3, 13].

Teachers have a diversity of methods and strategies at their disposal to inspire and develop student explanations [3]. Once the students have explanations and terms for their learning tasks, it is important to involve them in further experiences which extend, or *elaborate*, the concepts, processes, or skills [3, 13]. This level enables the transference of concepts to closely relate but new situations. Students' theoretical understandings and skills are challenged by their new experiences and by guidance of their teachers. They develop deeper and extensive understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting supplementary activities. Elaborative activities provide further time and experiences that contribute to learning.



Assess/evaluate				
5E-phases	Teacher role	Student role	Teacher	Student
Engage	Motivate, engage, and uncover prerequisites, context, and syllabus in focus	Enabling prerequisites, be engaged and motivated, formulate questions and make hypotheses	Assess/evaluate learner knowledge, and activity in relation to learning objectives and dividend	Assess/evaluate the knowledge and expertise and what is needed in order to achieve the learning objectives.
Explore	Suggest learning resources, varying methods, guiding	New experiences through exploration to find solutions, to communicate and discuss observations and new experiences develop new knowledge and perhaps relinquish old perceptions	Assess/evaluate the learning process in relation to the learning objectives, providing feedback to students on the exploratory activity	Assess/evaluate information and observations
Explain	Let students communicate their knowledge, introduce and use terminology, challenge students' explanations and summarize student' explanations	Observe and see connections, find and formulate an argument for their own explanations, and reflect on other explanations	Assess/evaluate students explanations give feedback on student academic argumentation, focus on student outcomes	Assess/evaluate information and scientific arguments, reflect on their own understanding by comparing and understanding different explanations
Elaborate	Summarize and transfer technical material, deepen and expand to other parts of the subject, asking open questions for further exploration	Develop a deeper and broader understanding, and use new knowledge in new contexts	Provide feedback on how the student can prepare and provide feedback on student learning	Assess/evaluate the learning process in relation to syllabus, and assess/evaluate the competence in relation to the learning objectives

**Table 1.**  
*Phases in model 5E, different roles (teacher/student) [3].*

*Evaluation* should be continuous, varied, and be a part of all levels [3, 13]. Evaluation concerns the activities and has a meta perspective on them. Assessment is on the individual level and concerns self- and peer assessment, continuous assessment and final assessment of processes and products. It can be conducted orally, in writing or in a combination. Students consider their own learning and understanding, and the teacher and/or peers will assess student learning in relation to learning objectives in each subject or in an activity, and in relation to the objectives of the curriculum.

Understanding how knowledge is constructed by an individual through active thinking in the form of selective attention, organization of information, and integration with or replacement of existing knowledge, and that accepting that social interaction is necessary to create shared meaning gives NOS a deeper-rooted

affiliation in cultures [15]. Based on this approach teachers might be stimulated to analyze their own practice, develop their understanding of the impact of their practice on students' learning, and to develop new ways of teaching by reflecting in their own classes.

IBL using makerspace might give students challenges in NOS and NOT they need both academically and practically [14]. An establishment of a makerspace at school may give room for enhanced creativity for students. A makerspace is a place in which students with STEM interests, especially in computing or technology, can gather to work on projects while sharing ideas, equipment, and knowledge. Digital fabrication is one of the key activities in makerspaces equipment such as 3D-printers, laser cutters and electronic elements are often available [16]. A skill often referred to when makerspaces are discussed is creativity through inquiry [17]. The concept makerspace has become so widespread it no longer needs to include a pre-defined set of fabrication tools; the focus is rather on having a creative space, where it is possible to explore, make and tinker [18]. Makerspaces can be the spot that encourages a whole new generation of creative minds to explore and solve the big problems [16]. It might give students a chance to see what they can do when they are not limited by classroom rules and answers. Some literature [19] explicitly mentions the intention of makerspaces to stimulate interest in STEM. Creativity is a valuable resource, and a makerspace is the perfect tool to enhance and harness it [16–18].

The 5E-model and use of IBL can also contribute to stimulate to *in-depth learning*, which is about the students' gradual development of understanding of concepts, methods, and contexts within a subject area, and about understanding themes and issues that moves across areas of knowledge [14]. In-depth learning means that students use their own abilities to analyze, solve problems and reflect on their own learning to construct a lasting understanding. Learning something thoroughly and with good understanding requires active participation through their own learning processes, the use of learning strategies and the ability to assess their learning progress [20].

## **8. The scientific- technological innovation**

Stimulating students' interest in science, technology, engineering and mathematics (STEM) has been of great concern for many years [2]. Another concern has been the need to develop 21st century skills, such as creativity, critical thinking, and collaboration, which are essential for the future [1]. Science as an enterprise has individual, social, and institutional dimensions. Scientific activity is one of the main features of the modern world [5].

As a social activity, science reflects social values and cultures. The direction of scientific research is affected by informal influences within the culture of science itself, such as prevailing opinion on what questions are most interesting or what methods of investigation are most likely to be productive [2]. In order to understand the importance of culture for human cognitive scientific development we could address Vygotsky [15]. Vygotsky developed a sociocultural approach to cognitive development. Vygotsky argued, "learning is a necessary and universal aspect of the process of developing culturally organized, specifically human psychological function" [15]. In other words, social learning tends to precede (i.e., come before) development. Vygotsky's theories stress the fundamental role of social interaction in the development of cognition [15], as he believed strongly that community plays a central role in the process of *making meaning*. For Vygotsky, the environment in which children grow up will influence how they think and what they think about.

Vygotsky assumes cognitive development varies across cultures, and the cultures need to be considered with the purpose to understand cognitive development [15].

## **9. Innovative teaching and learning**

An establishment of a makerspace at school may give room for innovative teaching leading to enhanced creativity for students. A makerspace is a workplace in which students with STEM interests, especially in computing or technology, can gather to work on projects while sharing ideas, equipment, and knowledge. Digital fabrication is one of the key activities in makerspaces equipment such as 3D-printers, laser cutters and electronic elements are often available [17]. A skill often referred to when makerspaces are discussed is creativity [16, 17].

The concept makerspace has become widespread it no longer needs to include a pre-defined set of fabrication tools, the focus is rather on having a creative space, accessible to the public where it is possible to explore, make and tinker [16, 17].

Some literature [e.g. 19] explicitly mentions the intention of makerspaces to stimulate interest in STEM. Makerspaces can be the spot that encourages a whole new generation of creative minds to explore and solve the big problems. This opportunity of learning gives students an innovative chance to experience what they can do when they are not limited by classroom rules and answers [14].

## **10. Further development of NOS and NOT**

It is not a question if development of science and technology will continue, but in which areas it will do so. A long-term growth of wealth will occur as a result of technological innovations. Considering NOS and NOT are essential for innovation and change and to ensure that we in the future will have a knowledge-based society that asserts itself in international rivalry [2, 21]. Many challenges in the society today are, and will increasingly be, of technological or scientific character. We need a solid basic competence in order to ensure that the development is going in the right direction, and that we will be able to enjoy the opportunities technological development will offer [11].

The world is now facing major challenges related to climate changes, medical challenges and energy needs as examples. These are challenges that cannot be answered without research and experimentation in science and technology. Scientists can bring information, insights, and analytical skills to stand on matters of public concern. They can help the public and politicians to comprehend the possible causes of events, such as natural disasters, and to predict the possible effects of projected policies i.e., such as ecological effects of various farming methods. Researchers in science can resolve exciting assignments related to for example; renewable energy, capture and storage of CO<sub>2</sub>, nanotechnology and biotechnology. In addition, the sciences will have more impact in the future based on new technologies that will appear and affect our everyday lives.

## **11. Summary**

NOS and NOT refers to principles and ideas which provide a description of science as a way of knowing, as well as characteristics of scientific knowledge [1, 2, 4, 5, 6]. In science and technology scientists attempting to look at the natural world objectively. Scientists attempt to make sense of observations of phenomena

by constructing explanations for them that use, or are consistent with, currently accepted scientific principles. Makerspaces as innovative learning and teaching can make students explore and solve experimental challenges [16, 17, 18].

The complex challenges that the world faces in the 21st century require a systematic reorientation of science and technology education in general [2]. The global challenges, with all their needed actions from local to global levels, need responses from science and society, and achievement will depend on the reorientation of education. Science in the future will depend on technological inventions as a mean of further development.

## Author details

Bodil Svendsen  
Department of Teacher Education, Norwegian University of Science and  
Technology, Norway

\*Address all correspondence to: [bodil.svendsen@ntnu.no](mailto:bodil.svendsen@ntnu.no)

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